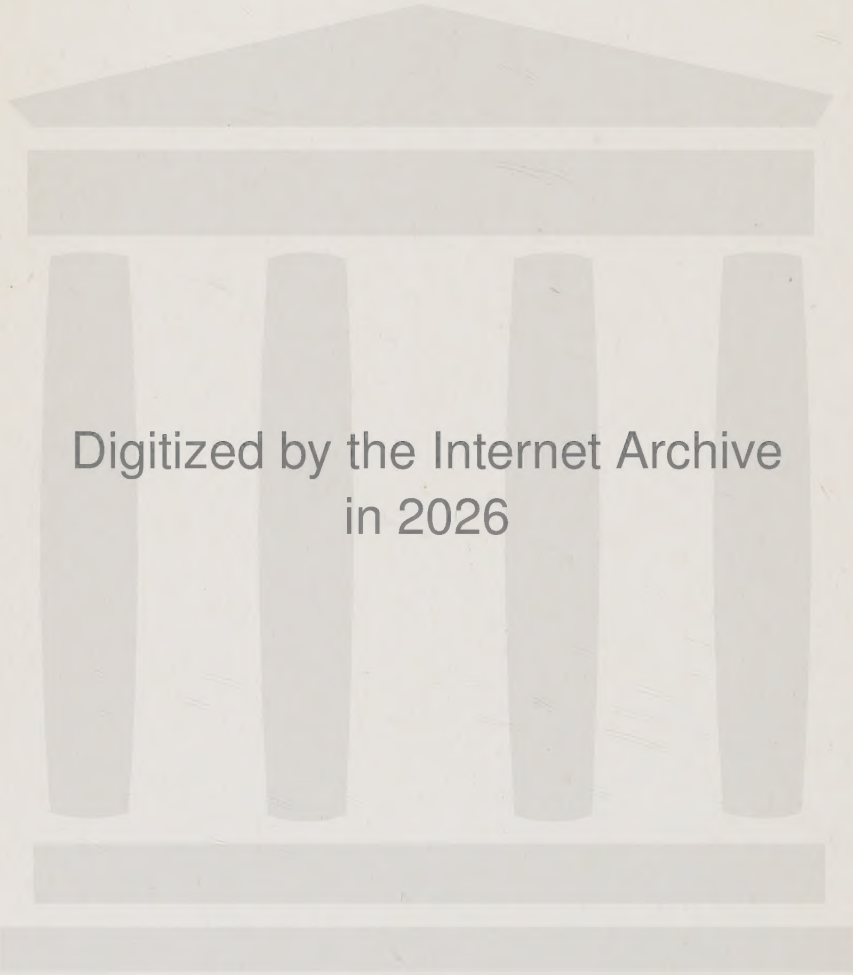


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INTRODUCED AT VARIOUS LEVELS
OF DIFFICULTY

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JOHN MAURICE WILLMANN

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THESIS

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THE EFFECT OF A FIXED CHANGE IN DIFFICULTY INTRODUCED AT VARIOUS LEVELS OF DIFFICULTY

By

JOHN M. WILLMANN

The present experiment supplements a series of experiments by Woodrow (2, 3, 4, 5, 6) dealing with the general problem of the relation between goodness of performance and the favorableness of conditions. The problem has been to discover how the goodness of performance on some task is affected by a fixed change in the difficulty of the task, when that change is introduced at various levels of difficulty, these different levels being produced by variations in some other one of the conditions under which the task is performed. Certain discrepancies had appeared in the results of the previous experiments and they were considered to be due perhaps to the fact that the investigations had involved different portions of the total range of difficulty. It was particularly desired then, in the present case, to introduce the fixed change in difficulty at levels of difficulty that would extend all the way from the very easy to the extremely difficult.

The task to be performed consisted in the naming of letters exposed tachistoscopically for .1 second. The letters were projected upon a screen, and the task was rendered more and more difficult, through seven different steps, by the simple process of decreasing the illumination. At each of these levels of difficulty the effect of two different fixed changes was observed. The one change was produced by increasing the separation of two letters, the other by increasing the number of letters from two to four. The problem was to find how these changes in difficulty would affect performance at each intensity of illumination.

The room in which the experiment was conducted was completely darkened so far as external light was concerned, and the subjects were made to sit in total darkness for a period of seven minutes each day before actual work was begun. With the eyes thus quite well dark-adapted, the room was internally

lighted by a small seven-watt bulb, which minimized the effects of whatever further adaptation might occur after the seven minutes.

The subjects, four in number, were employed two at a time, seated at a table with their chins resting in the grooves of two flat horizontal blocks of wood which were clamped to the table, and which were adjustable in height to suit the height of the subjects. With a subject thus seated, his eyes were exactly ten feet from the screen. The projector, a 500-watt Spencer Delineascope, was placed immediately behind the subjects so that the beam passed between their heads. The projector was 33 inches farther from the screen than the subjects' eyes. It was fitted with a special tin holder into which the paper slips containing the letters to be projected were inserted, so that the letters always had the same position when projected upon the screen.

Immediately in front of the lens of the projector was a Whipple tachistoscope, stripped of everything except the disc and the weighted arm to make it revolve. The lens of the projector was $3\frac{1}{2}$ inches in diameter, and the aperture in the tachistoscope was $5\frac{1}{2}$ inches. This aperture was such as to allow an interval of .1 second, as measured by the record of a tuning fork on a smoked paper, from the moment the lens was half uncovered until, after the full exposure of the lens, it was again half covered.

The screen was of white cardboard, 42 inches long and 18 inches high. In the center was a small black cross serving as a fixation point. At the signal of "ready", the subjects looked at this point, and the letters, whether close together or at the wider separation, and whether two or four in number, were projected symmetrically to the right and left of this point. The letters were Willson's gummed letters pasted on white slips of paper, and when projected upon the screen were $1\frac{1}{8}$ inches in height. And the spread between the letters of the widest separation when projected was $12\frac{3}{4}$ inches. Not all the letters of the alphabet were used because of the confusing similarities that exist between certain letters. The omissions were D, F, G, Q, and R. The subjects, however, were not informed of these omissions. The illumination was controlled by two resistors in series which could be set so as to reduce the voltage to any desired point from 110 down to 27.

The subjects were tested on three kinds of material: two letters with a separation on the projection screen of $4\frac{1}{4}$ inches, two letters with a separation of $12\frac{3}{4}$ inches, and four letters which actually were a combination of the other two types as shown in the following illustration:

Narrow separation		X	M	
Wide separation	A			P
Four letters	C	O	V	W

The slips on which the letters were pasted were assembled in sets of twenty each, and each set was run off without a break, just a few seconds elapsing between successive presentations, the time required for the experimenter to unload and reload the projector. During these brief intervals the subjects wrote down the letters they thought they saw. They were instructed

to do their best to see the letters correctly but that it was permissible to guess if they had even the faintest idea as to what the letters were. For a correct response it was required not only that a letter be named correctly but that it also be given its correct position in the group.

The seven intensities of illumination mentioned above were selected after two separate hours of preliminary testing, which served incidentally as a practice period. The data obtained from these testings were used to determine what upper and lower limits of illumination would make the task very easy in the one case and extremely difficult in the other, and to locate five intermediate intensities between these extremes which would be more or less evenly spaced as to difficulty. The intensities finally selected were those produced by currents of 50, 44, 37, 35, 33, 31, and 29 volts.

In the experiment itself, then, the subjects were tested at seven different intensities and with three different types of letter groups, making 21 combinations of conditions in all. In each of these combinations each subject was tested to the extent of 200 presentations. Not all intensities and types of letter groups could be tested on any one day, but the 21 combinations were distributed quite uniformly over the entire eighteen days of the experiment. By the end of the fourth day, each combination had been employed to the extent of 40 presentations; by the end of the ninth day, to the extent of 100 presentations; and the second nine days of the experiment duplicated the first nine. Also, the combinations of conditions were mixed or alternated considerably within each day, so that none of them might have an advantageous or disadvantageous position resulting from practice effects or from fatigue. A sufficiently large number of letter slips were available that the subjects could not become familiar with the groups of letters because of frequent repetitions.

The raw scores obtained, consisting of number of letters correctly named, were corrected for chance successes by the use of the formula (1), $S = R - \frac{W}{n-1}$, in which S is the corrected score, R the number of right responses, W the number of wrong

responses, and n the number of alternative responses. Since the subjects did not know that certain letters were never used, n was taken as 26, the number of letters in the alphabet. The corrected scores were next converted into percentage scores.

These percentage scores were then treated in such a way as to render them a more accurate measure of difficulty. In the method used, which has been discussed in detail in another paper (2), the simple assumption is made that the amounts of ability brought to bear upon the performance at successive trials by a single subject are normally distributed. On this assumption, it is possible to evaluate the difficulty of the task under any given set of conditions, and thus overcome an imperfection inherent in per cent scores. As here used, difficulty must be conceived to vary inversely with the amount of ability required under the given conditions to produce a correct response. Difficulty has therefore been evaluated on the basis of a normal distribution surface, by using as its measure a distance along the base-line measured in terms of the standard deviation, from the mean to the point at which a perpendicular would mark off a proportion of the surface equal to the proportion of correct responses. Thus, if under one set of conditions a subject correctly named 16 per cent of the letters and under another set of conditions 50 per cent, the difficulty for that subject of naming a letter correctly would be regarded as $x+0$ in the latter case and as $x+1.0$ in the former case. Similarly, the difficulty of any set of conditions may be evaluated in an absolute way from an arbitrary zero, provided only the score lies within the limits of zero and one hundred per cent correct.

Since the variability in the ability of different subjects would presumably not be the same, the data for each subject were in the first instance treated separately. If, however, it is a valid procedure to transform the per cent correct scores of a single subject into sigma values, it is probably sound, also, to transform the average per cents correct of all subjects used, since such average per cent correct scores are likely to be somewhat more representative of the scores made by any individual belonging to the same population from which the used subjects were chosen. An alter-

native procedure, which has a nearly identical outcome, is to average the sigma scores. Since the complete experiment, gone through by only four subjects, involved twenty-one sets of conditions, the results presented in this case will be limited to the average per cent correct scores and their sigma values. In the case of a supplementary experiment carried out with twelve subjects but involving only four sets of conditions, both individual and pooled scores will be presented.

The results of the complete experiment with four subjects are given in Table I. This table required the scoring of a total of 44,800 letters, of which one half, or 22,400, were exposed two at a time and the other half four at a time. The percentage correct in each of the 21 cells of the table is based on 800 exposures, and therefore is a percentage calculated from 1600 in

TABLE I

PER CENT CORRECT AND SIGMA SCORES UNDER TWENTY-ONE CONDITIONS

Illumination	Two Letters Narrow Separation		Two Letters Wide Separation		Four Letters	
	%	σ	%	σ	%	σ
I	90.90	-1.34	78.16	-.78	72.80	-.61
II	83.36	-.97	58.08	-.20	62.43	-.32
III	49.82	.01	29.67	.53	30.78	.50
IV	40.33	.25	20.57	.82	22.46	.76
V	25.64	.65	9.13	1.33	11.83	1.18
VI	10.76	1.24	3.80	1.77	4.39	1.71
VII	3.87	1.77	.68	2.47	1.33	2.22

the case of two-letter exposures and from 3200 in the case of four-letter exposures. Each per cent correct given in the table is the per cent correct for the pooled responses of the four subjects after the total number correct has been corrected for chance successes by the formula already given.

The basic problem is the drop in performance level, resulting at each illumination, from the change from the narrow separation to the wide, and from two letters to four. The change from two letters to four letters requires special treatment. We are concerned with the effect of a *single* change in the conditions when introduced at various levels of difficulty that are produced by some other change in conditions. Now the shift from two letters

to four is not a single change, for in addition to the change in number of letters there is also an alteration in the spread or position of the letters. No two letters can duplicate the pattern of four letters. It is the effect of the change in number alone that is sought, and the disturbing spatial factor must be eliminated. This was done by averaging the percentages correct for both narrow and wide 2-letter separations before taking the sigma value to be compared with that of the 4-letter series at the same intensity of illumination. For the 4-letter group, as already mentioned, is really a combination of the two letters at the narrow and at the wide separations. It follows that the change from the average of both 2-letter series to the 4-letter series represents

TABLE II
CHANGE IN DIFFICULTY AT VARIOUS ILLUMINATIONS DUE TO A FIXED
CHANGE IN EITHER SEPARATION OR NUMBER OF LETTERS

Illumination	Change in Separation (from narrow to wide)	Change in Number (from two to four)
I	.56	.41
II	.77	.23
III	.52	.24
IV	.57	.25
V	.68	.25
VI	.53	.25
VII	.70	.22

that change from "2-ness" to "4-ness" which is desired. Similarly, the fixed change from two letters at the narrow separation to two letters at the wide separation represents only a change in separation, without the factor of number of letters entering in.

The effect of these two fixed changes is shown in Table II. The first column of differences represents the increase in difficulty (sigma score), at each intensity, caused by increasing the separation of the two letters, and the second column the increase in difficulty caused by the change from two letters to four letters.

In the shift from the narrow to the wide separation the drop in performance level, as measured by the sigma values, is irregular; but when viewed across the whole range of intensities, the data indicate constancy of effect rather than any general trend towards either increase or decrease. The best fitting straight line would be practically horizontal. It is concluded, therefore, that

the data obtained indicate a general tendency towards constancy in the effect of a fixed increase in the separation of two letters, no matter at what illumination the fixed increase is introduced.

The effect of the change from 2 to 4 letters is slightly less certain. The results indicate a rather marked decrease in the effect of the increase in number of letters as the illumination drops from level I to level II, but a remarkable constancy in the effect of this fixed change in number throughout levels II to VII inclusive.

TABLE III

PERCENTAGE AND SIGMA SCORES FOR TWO LETTERS UNDER FOUR SETS OF CONDITIONS

Illumination	Bright				Dim			
	Narrow		Wide		Narrow		Wide	
Separation								
Subject	%	σ	%	σ	%	σ	%	σ
F	87.98	-1.17	69.13	-.50	51.58	-.04	28.83	.56
K	91.88	-1.40	78.23	-.78	62.30	-.31	30.78	.50
De	78.23	-.77	52.88	-.07	26.23	.64	15.50	1.01
Dr	71.08	-.55	42.23	-.05	22.00	.77	10.95	1.23
J	87.00	-1.13	65.88	-.41	42.15	.20	21.35	.79
B	89.28	-1.24	71.73	-.57	32.73	.45	15.83	1.00
H	37.60	.32	23.63	.72	3.80	1.77	2.18	2.01
Mo	91.88	-1.40	78.88	-.80	51.25	-.03	26.55	.63
Mc	89.28	-1.24	77.25	-.75	60.68	-.27	26.55	.63
W	83.43	-.97	65.88	-.41	37.28	.32	14.85	1.04
O	88.30	-1.19	66.53	-.43	36.95	.33	18.45	.90
S	83.75	-.97	62.63	-.32	28.50	.57	5.75	1.58
Pooled Scores	81.74	-.906	63.73	-.351	37.95	+.307	18.13	+.910
Mean of σ Scores		-.976		-.364		+.367		+.990

The first of the above conclusions, to the effect that a given increase in separation tends to exert a constant effect at all illuminations, for reasons to be explained later is considered to be extremely important. It was therefore subjected to further test by a supplementary experiment employing twelve subjects. This experiment differed from the preceding one in that only two intensities of illumination were used, namely, II and IV of the preceding experiment, and in that only 2-letter slips were used. Both the average scores made by the group and the individual scores are shown in Table III. One hundred and sixty slips were presented to each subject under each of the four sets of conditions. It follows that each individual score is the percentage

correct (corrected by formula) of 320 letters. The average percentage correct (also corrected) given in the second line from the bottom is in each case the percentage correct of 12×320 letters or 3,840 letters. The entire table required the scoring of 15,360 letters.

It will be observed from Table III that the difference between illuminations II and IV was sufficient to produce a great difference in difficulty. Thus, with the brighter illumination the

TABLE IV
THE EFFECT OF A FIXED CHANGE IN SEPARATION OF LETTERS AT TWO
DIFFERENT LEVELS OF ILLUMINATION

Subject	Bright (II)	Dim (IV)	Diff. (IV-II)
F	.67	.60	— .07
K	.62	.81	.19
De	.70	.37	— .33
Dr	.50	.46	— .04
J	.72	.59	— .13
B	.67	.55	— .12
H	.40	.24	— .16
Mo	.60	.66	.06
Mc	.49	.90	.41
W	.56	.72	.16
O	.76	.57	— .19
S	.65	1.01	.36
Pooled Scores	.555	.603	.048
Mean of differences in sigma scores			.012
$\sigma_{dis.}$ of differences			.218

average percentage correct for the narrow separation was 81.74 while with the dimmer illumination it was only 37.95. The effect of this change in level of difficulty upon the effect of the fixed change in separation of the letters is shown by Table IV. The first column of Table IV, headed "Bright (II)", shows the increase in difficulty (in sigma scores) produced by the increased separation when the illumination was relatively bright (at level II); and the second column, the same effect when the illumination was relatively dim (at level IV). The third column shows the difference in the effect of increased separation at the two levels of illumination. This column reveals that individual differences are rather pronounced. With some subjects the effect of the increase in separation is greater with bright illumination and with

others at dim illumination. On the average, however, there is no significant difference, since the mean discrepancy between the effect of increased separation at the two illuminations (.012) is only about one-nineteenth of the standard deviation of the distribution of the 12 cases (.218).

It happens that, in the present instance, even in terms of percentage correct scores (pooled scores), the effect of increase in separation may be seen to be practically the same at both levels of illumination. The reason that this is possible is presumed to lie in the fact that the lowest percentage score (18.13, with illumination IV and wide separation) is above zero almost the same amount that the highest percentage score (81.74, with illumination II and narrow separation) falls short of one hundred. It thus happens that the changes in the percentage scores are comparable. Change from narrow to wide separation with illumination II causes a drop in the percentage correct scores from 81.74 to 63.73, or 18.01, while the change from wide to narrow separation at illumination IV causes an increase of nearly equal magnitude—one from 18.13 to 37.95, or 19.82.

It may be concluded, then, that the supplementary experiment with twelve subjects verifies the conclusion drawn from the more elaborate investigation with four subjects as regards the effect of a fixed change in letter separation at different levels of difficulty when the latter are produced by variation in illumination. Both experiments indicate that the effect of the fixed change tends to remain constant at the different levels of difficulty.

As already stated, the problem here studied is identical with one studied in a series of investigations by Woodrow, namely, that of the effect of a fixed change in conditions at various levels of difficulty. Certain inconsistencies had appeared upon which it was hoped some light would be thrown by the present experiment. One of these previous experiments (4) dealt with reaction-time. In that experiment the subject's task consisted of reacting as quickly as possible in response to a flash of light. Different levels of difficulty were produced by varying the intensity of this light throughout a wide range. The fixed change introduced at these different levels of difficulty consisted in the shift from a

standard preparatory interval (the time between the "ready" signal and the flashing of the light) of exactly 2 sec. duration, to a variable preparatory period ranging from 2 to 24 sec. The reaction-time scores in thousandths of a second were changed, by means of an absolute scaling technique, into scores representing goodness of performance. It was then found that the effect of the fixed change in the length of the preparatory period exerted a constant effect upon goodness of performance at all the different levels of difficulty produced by varying the intensity of the light. This result is in harmony with the findings in the present experiment.

In another investigation (3:I) the procedure was quite similar to that followed in the present experiment. The subjects were required to name letters exposed tachistoscopically. The fixed change in conditions was a shift from two letters to four, but the different levels of difficulty at which this change was introduced were produced, not by decreasing illumination, but by increasing the distances between the letters. Here again constancy was found for the effect of the fixed change from two to four letters introduced at the various levels of difficulty.

In a subsequent experiment (3:II), however, some different results were obtained, partly agreeing and partly disagreeing with the previous findings. In this experiment changes in three conditions were utilized, namely, the number of letters, the illumination, and the spacing between the letters. In this study, the effect of a fixed change did not always remain constant, but sometimes decreased with increase in difficulty. The author, however, concluded as follows: "It follows that in any experimental work in which the investigator finds that a fixed change does not exert a constant absolute effect at all levels of difficulty, he should immediately search for a factor which he has not kept constant . . . which varies . . . with change in the conditions variation in which produced the different levels of difficulty at which this fixed change was introduced" (3:II, p. 128).

The general conclusions just stated were later modified because of results obtained in still another experiment (6) in which a new change in conditions was used, namely, the length of time the

letters were exposed. Exposures of .100, .020, .015, and .010 sec. were used. These variations produced the different levels of difficulty, and the fixed change introduced at each level was the change from 2 to 4 letters. The fixed change had a decreasing effect as the task became more difficult. This outcome suggested a new explanation of the fact that under some conditions increase in difficulty lessened the effect of a fixed change in conditions. This explanatory hypothesis rested upon the fact that a review of the previously obtained data revealed that constancy in the effect of a fixed change in conditions had been obtained only at relatively high levels of performance and with relatively small fixed changes. The hypothesis was therefore advanced that while the effect of a fixed change is constant, or nearly so, at easier levels, it becomes progressively smaller with further increases in difficulty once a high level of difficulty is reached. Such results would be accounted for, it was pointed out, on the basis of a certain curvilinear relationship between scaled scores and the favorableness of conditions.

The present experiment was undertaken with a view to testing this latter hypothesis by investigating levels of difficulty ranging from the very easy to the extremely difficult. These latter levels were certainly reached, for at the dimmest illumination scores little better than pure chance were secured. Yet throughout this wide range in levels of difficulty, the effect upon difficulty of the fixed increase in separation of two letters showed no general tendency to decrease with increase in difficulty. It follows that the relationship between goodness of performance and favorableness of conditions is linear, or very nearly so. It seems, therefore, that those cases in which a decrease occurs in the effect of a fixed change with increase in difficulty can be explained only in terms of Woodrow's original hypothesis concerning them, briefly indicated by the citation given above.

The results here obtained concerning the fixed change from 2 to 4 letters, with only slightly less certainty, indicate the same conclusion. There did occur, however, a decrease between the highest and next highest illumination in the effect of this change. Moreover, it is quite possible that had the change been from 2 to

6 letters there would have been observed a more marked decrease in the effect of the change in number with decrease in illumination. Such a result would be in line with Woodrow's finding that the change from 2 to 4 letters had a constant effect at various levels of difficulty produced by variation in either the separation or the illumination of the letters, but that the change from 2 to 6 letters had an effect which decreased with increase in the level of difficulty.

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VITA

John Maurice Willmann was born in Kankakee, Illinois, on the twentieth of June, 1906. He was trained in the elementary schools of that city and entered the Kankakee High School in the fall of 1920. He was graduated from this school in June, 1924. After attending Wheaton College for one year he transferred to the University of Illinois in 1926 and remained there for two years. He reentered this university in 1934 and completed his A.B. degree in 1935. He then studied in the Department of Psychology of the graduate school and received the degree of M.A. in 1936. From 1936 until 1938 he was employed as research assistant in the Laboratory of Physiological Psychology, and has since been engaged in other research.

